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Research Article

Invasive fish species in Romanian freshwater. A review of over 100 years of occurrence reports

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Abstract

Effective management of invasive alien species requires location-specific strategies involving the regular update of distribution maps to identify spatial patterns, trends, and pathways of entry and the spread and hotspots of those invasions. However, a comprehensive overview of invasive alien fish species in Romania is lacking. To fill this gap, we compiled a database with occurrences of alien fish species in Romania from diverse sources, including published literature, our own field data, online databases, social media, and online questionnaires. Occurrence data covers the 1910–2022 period. From a total of 52 alien fish species reported as present in Romania's waterways, we assigned an invasive status to 11 species, of which *Pseudorasbora parva*, *Lepomis gibbosus*, *Carassius gibelio*, and *Ameiurus* spp. are widespread. Based on the currently available occurrence records, we evaluated the presence and distribution of invasive alien fish species at the watershed level, concluding that invasive alien fish species are present in all Romanian watersheds. We identified several hotspots consistent with the main points of entry and spread of invasive alien fish species, principally located in western, central, and eastern Romania, i.e., Mures, Crisuri, and Siret watersheds.

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Introduction

Biological invasions are one of the main drivers of biodiversity decline, coupled with land use changes, overexploitation, climate change, and pollution (IPBES 2023; Roy et al. 2024). The number of invasive alien species is rapidly increasing worldwide, and there is no substantial evidence that the rate of establishment of new invasive species is decelerating (Mormul et al. 2022). Biological invasions often have complex and long-term direct and indirect impacts, and many of these events manifest decades later, when the invaders are well established across large geographic ranges (Pyšek et al. 2020). Invasive alien species, such as the zebra mussel (*Dreissena polymorpha*), cane toad (*Rhinella marina*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Hypophthalmichthys nobilis*), grass carp (*Ctenopharyngodon idella*) and European starling (*Sturnus vulgaris*) have noticeably disrupted

ecosystems worldwide, leading to lasting ecological harm (IPBES 2023). Asian carp, for example, outcompetes native fish, reducing biodiversity and disrupting aquatic food webs (Pimentel et al. 2005; Mayer et al. 2021). The negative impact on biodiversity of invasive alien species is accelerating and is expected to increase in the future. Researchers and policymakers proposed several measures to minimise future invasions; however, insufficient funding and limited scale of interventions reduce their efficiency (Seebens et al. 2017; IPBES 2023; Roy et al. 2024).

Invasive alien fish species pose a significant global threat to freshwater, estuarine, and marine ecosystems (Katsanevakis et al. 2013; Nunes et al. 2015), and freshwater ecosystems are considered among the most affected globally by biological invasions (IPBES 2023). Moreover, due to their high economic and social impact, freshwater fish invasions are one of the most documented events, with numerous studies available discussing those invasive alien species, their ecology, invaded regions, pathways, impacts, and management options (FAO 2019; Schneider et al. 2021; Bernery et al. 2022). Most established alien fish species occur in temperate regions of Europe, North America, and South America.

The primary introduction pathways of alien freshwater species in Europe are stocking and aquaculture, where individuals are able to reproduce in their new environment and manage to escape and end up populating entire watersheds (Gherardi et al. 2009). Zieritz et al. (2016) however, outlines various introduction pathways occurring at different periods in Northwestern Europe. Since 2000, there has been a significant increase in accidental introductions compared to deliberate ones. Furthermore, species introduced for aquaculture, research, or ornamental reasons were introduced later in time than those introduced for biological control or leisure. Since the 1960s, the ornamental trade has grown substantially and was accountable for almost all deliberate introductions in Northwestern Europe (Zieritz et al. 2016; Bernery et al. 2022). A recent study on the invasion history of alien fish species in Germany and Austria indicates that, while fisheries (including aquaculture) and the animal trade were responsible for most earlier introductions, waterways were the main pathway for recent invaders (Rabitsch et al. 2013).

Alien freshwater species impact native fish species through predation, competition, hybridisation, and disease propagation (Cucherousset and Olden 2011; Truhlar et al. 2014; Findlay et al. 2015; Tran et al. 2015; Britton 2023). Additionally, they negatively impact native aquatic communities, resulting in economic losses to the fishing and tourism industries and compromising human health and well-being (Tricarico et al. 2016; Haubrock et al. 2022).

In response to the mounting concern posed by invasive alien species (IAS) and the need for supranational coordinated actions, the EU adopted the Invasive Alien Species Regulation (Regulation 1143/2014). This legislation currently includes a list of 88 invasive alien species of EU concern for which Member States are required to initiate measures such as eradication and control. The last updated list contains ten alien fish species of EU concern: *Ameiurus melas*, *Gambusia affinis*, *Gambusia holbrooki*, *Lepomis gibbosus*, *Morone americana*, *Channa argus*, *Perccottus glenii*, *Plotosus lineatus*, *Pseudorasbora parva* and *Fundulus heteroclitus* (European Union 2022).

In Romania, data on the presence and distribution of alien fish species is limited and often outdated. Prior to 1956, alien fish species commonly spread naturally from neighbouring countries. However, after 1956, the implementation of large-scale national stocking programs of alien fish species led to unintentional introductions (Decei 1981; Popa 2002). Salmonids were introduced in mountain lakes,

followed by minnows (*Phoxinus* spp.) used as baitfish. Several previous studies (Gavriloaie et al. 2003; Iftime and Iftime 2021) have enumerated or documented the presence and distribution of alien fish species in Romania. However, the available information is generally restricted to a few records, often old. To contribute to the management of alien fish species in Romania and Europe, the objectives of this study are (i) to update the inventory of alien freshwater fish species in Romania and identify the species that meet the criteria for invasiveness; (ii) to map the distribution of invasive alien freshwater fish species in Romanian freshwater and identify the hotspots and pathways to their spread.

Materials and methods

Data collection

We collected occurrence data from various sources published up to end of 2022, namely, scientific and grey literature, social media, public databases, online questionnaires, and our own field data, mainly collected during the 2019–2022 time frame of a national survey project (Ministry of Environment and University of Bucharest 2023).

Literature data were extracted from peer-reviewed articles, conference articles, books, grey literature, doctoral theses, and technical reports regarding the occurrence and distribution of alien fish in Romania. Initially, we used literature collected over the years by the authors. In addition, we searched Google Scholar and Web of Science All Databases collection, using a combination of keywords: alien fish, allochthonous fish, invasive fish, dispersal, distribution, new fish, nonnative fish, non-native fish, AND Danube, Danube Delta, Balkans, Bulgaria, Hungary, Moldavia, Romania, Serbia, Ukraine. We used the names of neighbouring countries as keywords because of the presence of border rivers, such as the Danube River, which is neighbouring Ukraine, Bulgaria and Serbia. The reference sections of the publications identified were further screened for other potentially relevant articles not covered by the search engines used.

Data on alien fish occurrences were also downloaded from the Global Biodiversity Information Facility (GBIF), a validated public online database (https://www.gbif.org/). Additionally, we collected data from social networking platforms (i.e., Facebook), where anglers and other fish-related peers submitted reports regarding invasive species. We only validated Facebook postings that had accompanying photos that allowed accurate species identification. Furthermore, an online survey was sent to fish researchers from different Romanian institutions.

Occurrence records are structured in a database that contains the following attributes: ID, Species, Source, Year of recording, Latitude, Longitude, Toponym, and Habitat. The occurrence database is limited to invasive alien fish species in Romania since the majority of the remaining alien fish species have very few occurrence records.

Data analysis

To enable spatial representation, we first standardised and geo-referenced occurrence reports of invasive alien fish species using a 10 km × 10 km UTM grid. We overlaid the 11 river management areas matching the Romanian Waters Authority

(i.e., Crisuri, Somes-Tisa, Siret, Prut-Barlad, Dobrogea-Litoral, Ialomita-Buzau, Arges-Vedea, Olt, Jiu, Banat, Mures) onto the grid map of Romania to conduct the analysis at the catchment level. As a result, each occurrence record was geo-tagged to a specific basin, allowing us to generate river basin statistics. To identify the hotspots, we used the Density Analysis Plugin with the Styled Heatmap function available in QGIS software. This function is integrated into the QGIS Heatmap algorithm (Kernel Density Estimation), automatically styling the layer and enabling users to set the cell size in different units of measure (QGIS.org 2023). Consequently, we selected kilometres as the base unit of measurement and set a kernel radius of 10 km with a uniform kernel shape and a greyscale ranging from 1 (light colour) to 60 (dark colour) to present the number of occurrences inside the radius.

Alien fish species present in Romania

We classified alien fish reported as present in Romania by invasion stage (Blackburn et al. 2011) (Fig. 1) as casual alien species, naturalised alien species, or invasive alien species (Suppl. material 1). Casual alien species (CAS) include alien fish species that have been observed and reported in the wild, sometimes on a single occasion. They are either aquarium fish that possess the ability to survive in a new environment or species that have been accidentally released from fish farms and are unable to reproduce or survive winter. Naturalised alien species (NAS) refer to species that have successfully adapted, forming self-sustaining populations, but which have not spread into new watersheds. The invasive alien species (IAS) category

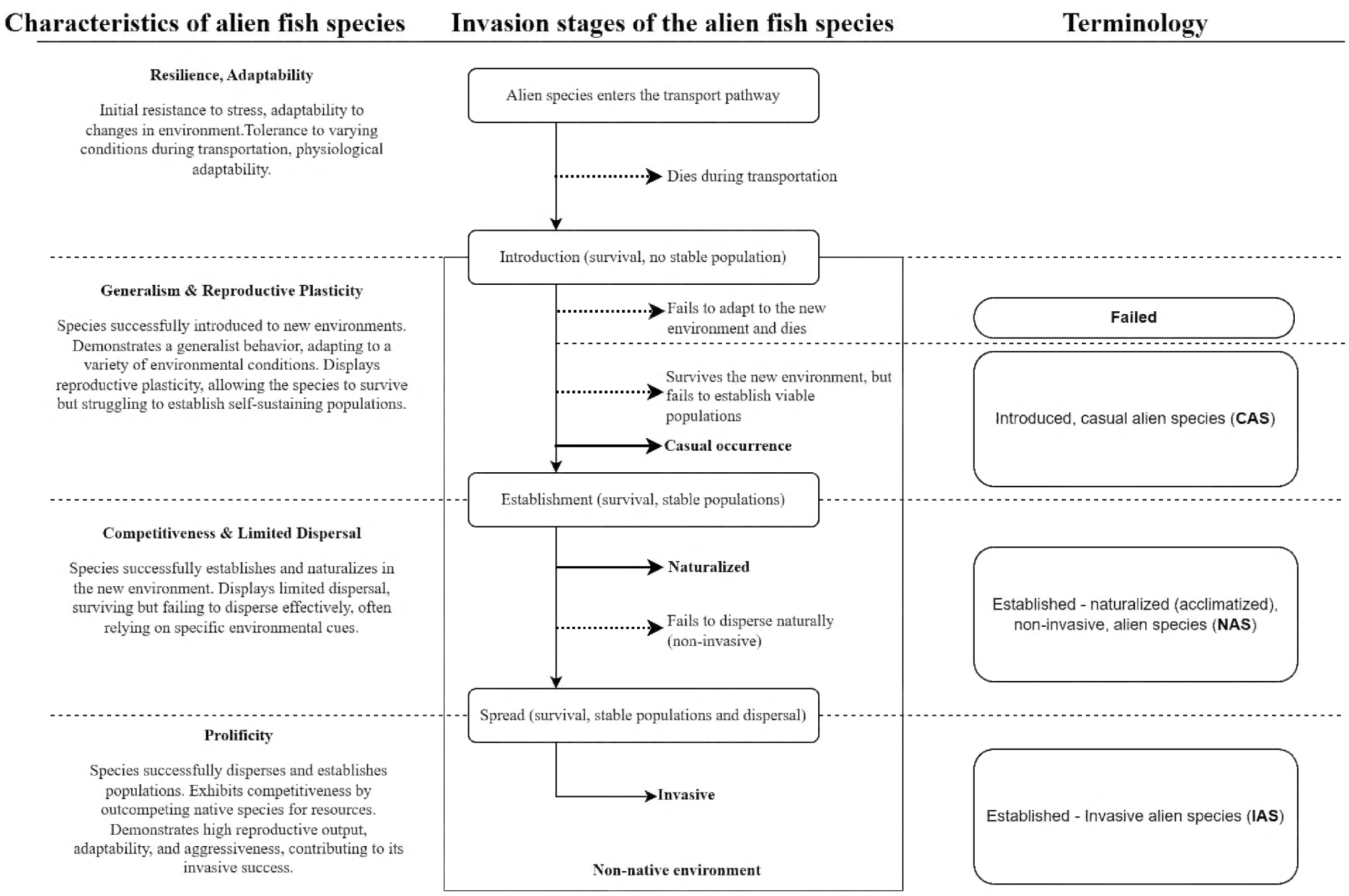


Figure 1. The main steps of the invasion process and the associated alien species status terminology used in this article.

includes species able to survive and outcompete native species, that possess advantageous reproductive features, demonstrate significant tolerance to environmental factors variation, and establish populations capable of spreading into new watersheds and habitats. Apart from these three categories, there are species for which we have limited data regarding their presence and impact (unknown/data deficient alien species) and species that failed to survive after introduction (Failed). We included *Carassius gibelio* in the list of IAS despite its unclear alien status. It was originally considered alien (e.g., Banarescu 1964; Iacob and Petrescu-Mag 2008), although later several authors considered it indigenous not only to Siberia but also to Central and Eastern Europe (Rylkova et al. 2013; Fricke et al. 2021). For Romania, Otel (2019) used historical distribution data to suggest that its natural range included the Romanian sector of the Danube and its main tributaries.

Results

We found 52 alien fish species reported in Romania between 1910 and 2022. Several sources reporting these species also included evidence on the pathway and year of introduction. From the 52 species reported from Romania, 11 fish species (Table 1) fulfil the criteria for invasiveness (IAS), the remaining (Table 2) are CAS (10 species), NAS (4 species), or have an unknown status (3 species). Furthermore, we identified 24 species that have failed to adapt and survive, including tropical aquarium species occasionally reported in the wild and surviving, at least, the summer (Table 2).

Apart from IAS, the rest of the alien fish reported in Romania have few distribution records. Therefore, we focused our study on the distribution of IAS species only (Table 1) and compiled a distribution database with 3107 occurrence records (https://ipt.pensoft.net/resource?r=invasive_fish_species_romania). Most occurrences were recorded starting with the 1990–2000 decade, with a peak in the 2000–2010 decade (Fig. 2). Of these, 2372 occurrence records were from published literature (98 documents, Suppl. material 2), 588 occurrence records were provided by the recent national survey project completed with our own field data, 78 occurrence records were extracted from the GBIF database, 22 occurrence records were extracted from social media, and 47 occurrence records were obtained from online questionnaires.

Table 1. Invasive alien fish species in Romanian freshwater.

Scientific name	Year of introduction	Natural range	Introduced from	Pathway
Ameiurus melas	1997	North America	Hungary	Unaided
Ameiurus nebulosus	1908	North America	Hungary	Unaided
Carassius gibelio	1912	East Asia	Moldavia	Aquaculture, Angling
Ctenopharyngodon idella	1960	South Asia	China	Aquaculture
Hypophthalmichthys molitrix	1960	South Asia	China	Aquaculture
Hypophthalmichthys nobilis	1960	South Asia	China	Aquaculture
Lepomis gibbosus	1929	North America	Hungary	Unaided
Oncorhynchus mykiss	1885	North America	Hungary	Angling
Perccottus glenii	2001	East Asia	–	Unaided
Pseudorasbora parva	1960	North-East Asia	China	Contamination of stocking
Salvelinus fontinalis	1906	North America	Austria	Angling

Table 2. Alien fish species with casual (CAS), failed, naturalised (NAS), and unknown status reported from Romania.

Scientific name	Year of introduction	Natural range	Introduced from	Pathway	Status
Acipenser baerii	2000	North Asia	Former USSR	Aquaculture	CAS
Betta splendens	2009	South-East Asia	–	Ornamental	Failed
Carassius (*auratus*) *auratus*	1920	East Asia	China	Aquaculture, Ornamental	NAS
Chindongo demasoni	2019	Africa	–	Ornamental	Failed
Clarias gariepinus	2002	North Africa	Hungary	Aquaculture	Unknown
Clarias ngamensis	2004	Africa	–	Aquaculture	Unknown
Coregonus albula	1956	North Asia	Former USSR	Aquaculture	CAS
Coregonus lavaretus	1956	North Asia	Former USSR	Aquaculture	
Coregonus peled	1980	North Asia	Former USSR	Aquaculture	NAS
Gambusia holbrooki	1927	North America	Germany	Biological control	NAS
Hemiculter leucisculus	1960	East Asia	China	Accidental	Failed
Ictalurus punctatus	1978	North America	Former USSR	Aquaculture	NAS
Ictiobus bubalus	1978	North America	Former USSR	Aquaculture	CAS
Ictiobus cyprinellus	1978	North America	Former USSR	Aquaculture	CAS
Ictiobus niger	1978	North America	Former USSR	Aquaculture	CAS
Lithochromis rufus	2019	Africa	–	Ornamental	Failed
Macropodus opercularis	–	East Asia	–	Ornamental	Failed
Megalobrama terminalis	1960	East Asia	China	Aquaculture	Failed
Micropterus salmoides	1912	North America	–	Angling	Unknown
Morone saxatilis	2018	North America	–	Angling	Failed
Mylopharyngodon piceus	1960	East Asia	China	Aquaculture	CAS
Ochetobius elongatus	1960	East Asia	China	Accidental	Failed
Oreochromis niloticus	2008	Africa	–	Aquaculture	CAS
Parabramis pekinensis	1960	East Asia	China	Aquaculture	Failed
Pethia conchonius	2008	South Asia	–	Ornamental	Failed
Pethia ticto	2001	South-East Asia	–	Ornamental	Failed
Piaractus brachypomus	2017	South America	–	Ornamental	Failed
Piaractus mesopotamicus	2021	South America	–	Ornamental	Failed
Poecilia reticulata	2008	South America	–	Ornamental	Failed
Poecilia sphenop	2008	South America	–	Ornamental	Failed
Polyodon spathula	1992	North America	USA	Aquaculture	CAS
Pseudobrama simoni	1960	East Asia	China	Accidental	Failed
Pseudolaubuca engraulis	1960	East Asia	China	Accidental	Failed
Pygocentrus nattereri	2022	South America	–	Ornamental	Failed
Salvelinus alpinus	2012	North America	–	Aquaculture	CAS
Squaliobarbus curriculus	1960	East Asia	China	Accidental	Failed
Toxabramis argentifer	1960	East Asia	China	Accidental	Failed
Trichopodus trichopterus	2008	South-East Asia	–	Ornamental	Failed
Xenocypris macrolepis	1960	East Asia	China	Accidental	Failed
Xiphophorus helleri	2008	Central America	–	Ornamental	Failed
Xiphophorus maculatus	2008	Central America	–	Ornamental	Failed

We ranked the invasive alien fish species based on the number of occurrence records as a surrogate index of spread and abundance; the most abundant is *Pseudorasbora parva*, while the least abundant is *Salvelinus fontinalis* (Fig. 3).

The spatial distribution of invasive alien fish species is uneven as most occurrence records were from the Mures River Basin and Cris River Basin, followed by the Siret River Basin and Somes-Tisa River Basin (Fig. 4). The lowest number of records were reported from the Jiu, Olt, and Prut River Basins.

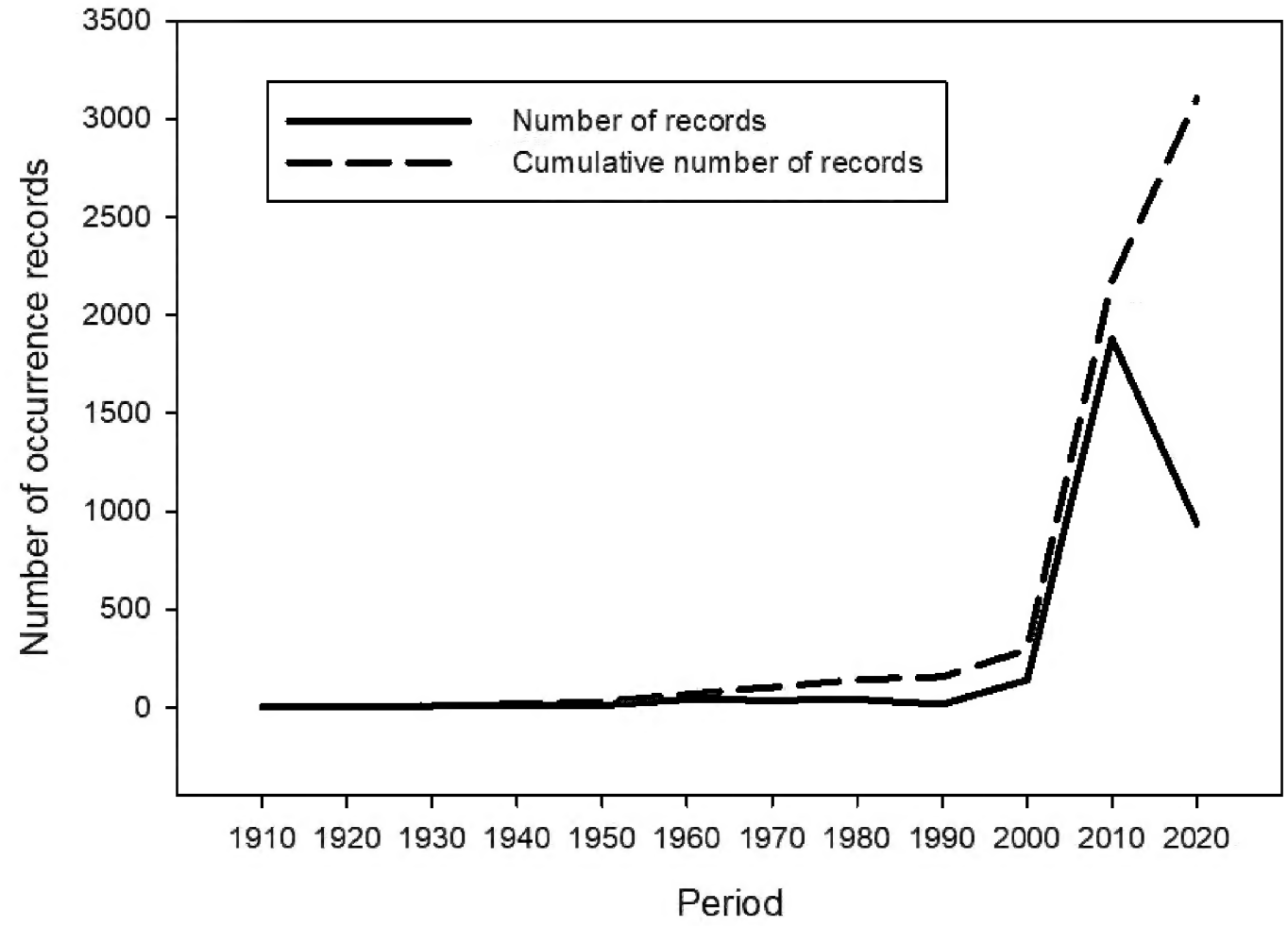


Figure 2. The number of occurrence records reported from Romania by decade (1910–2022).

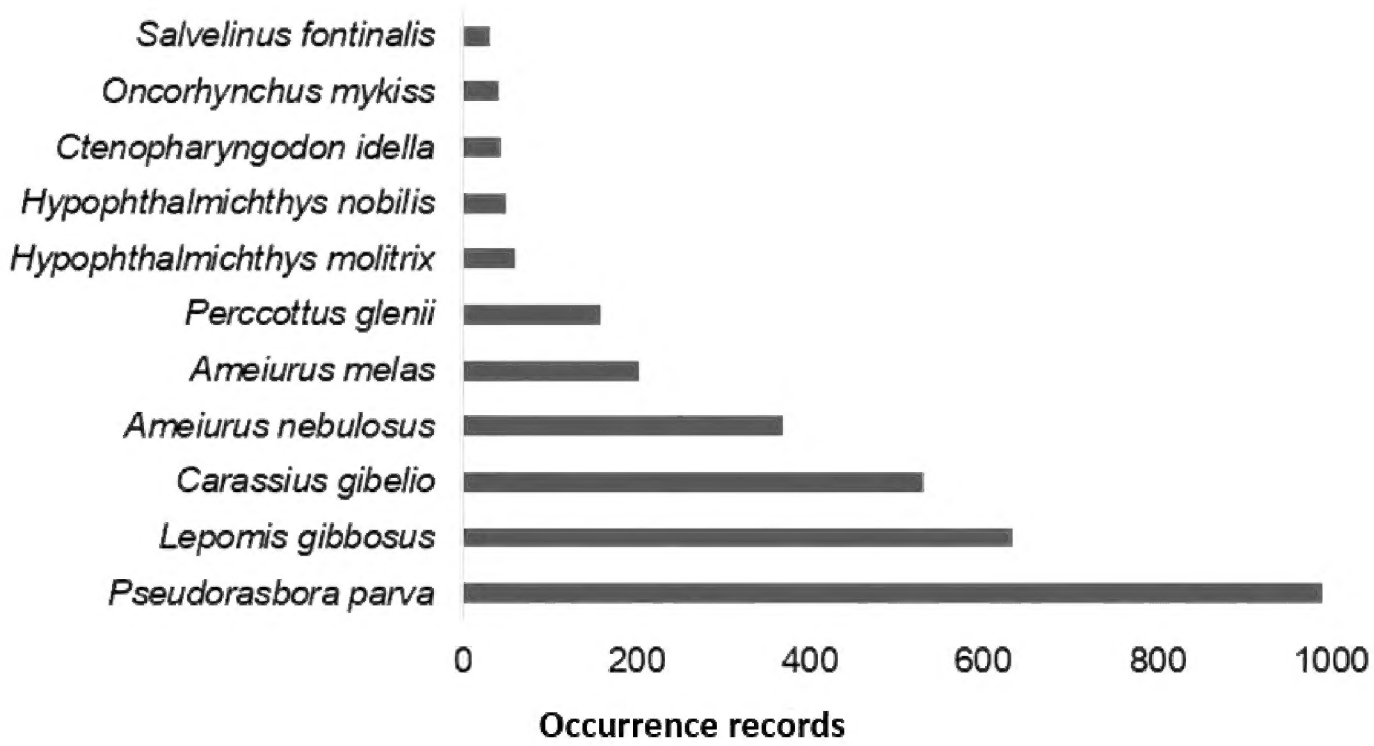


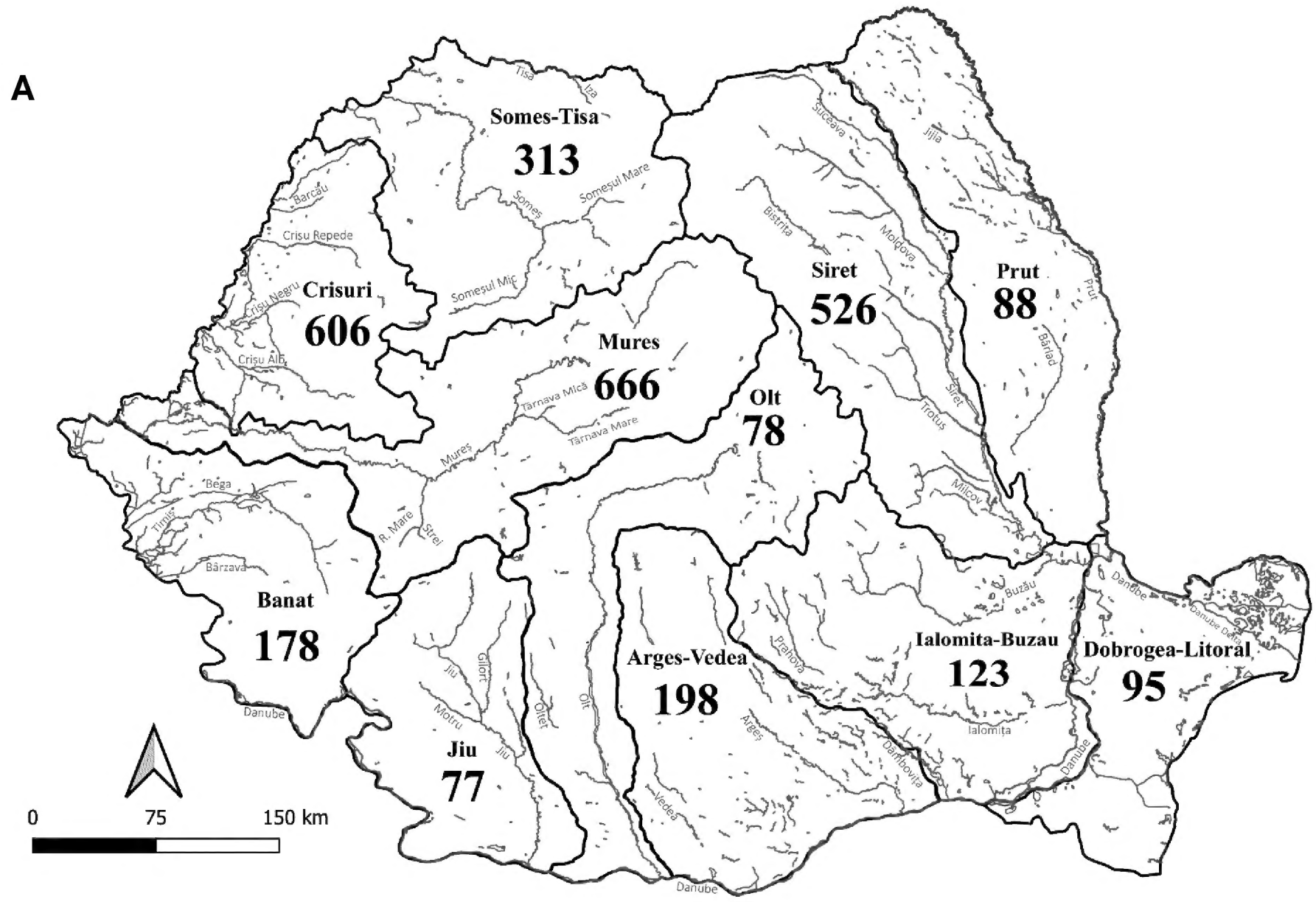
Figure 3. The total number of occurrence records of the 11 invasive alien fish species in Romania.

Spatial distribution of invasive alien fish species in Romania is presented in Fig. 5.

The visualisation of the hotspots highlights clusters of invasive alien fish species occurrences. These include the Danube, Crisuri and Mures rivers in the west and the Siret River and the Danube Delta in the east (Fig. 6).

Discussion

Our review identified 11 invasive alien fish species out of 52 alien fish species reported in Romania from 1910 to 2022. Within the invasive alien species of EU concern, we did not consider *Gambusia holbrooki* as invasive in Romania due to its restricted presence in a few lakes since their first detection decades ago and its inability to disperse naturally in lotic habitats. However, according to EU Regulation 1143/2014, this species should be eradicated if detected.



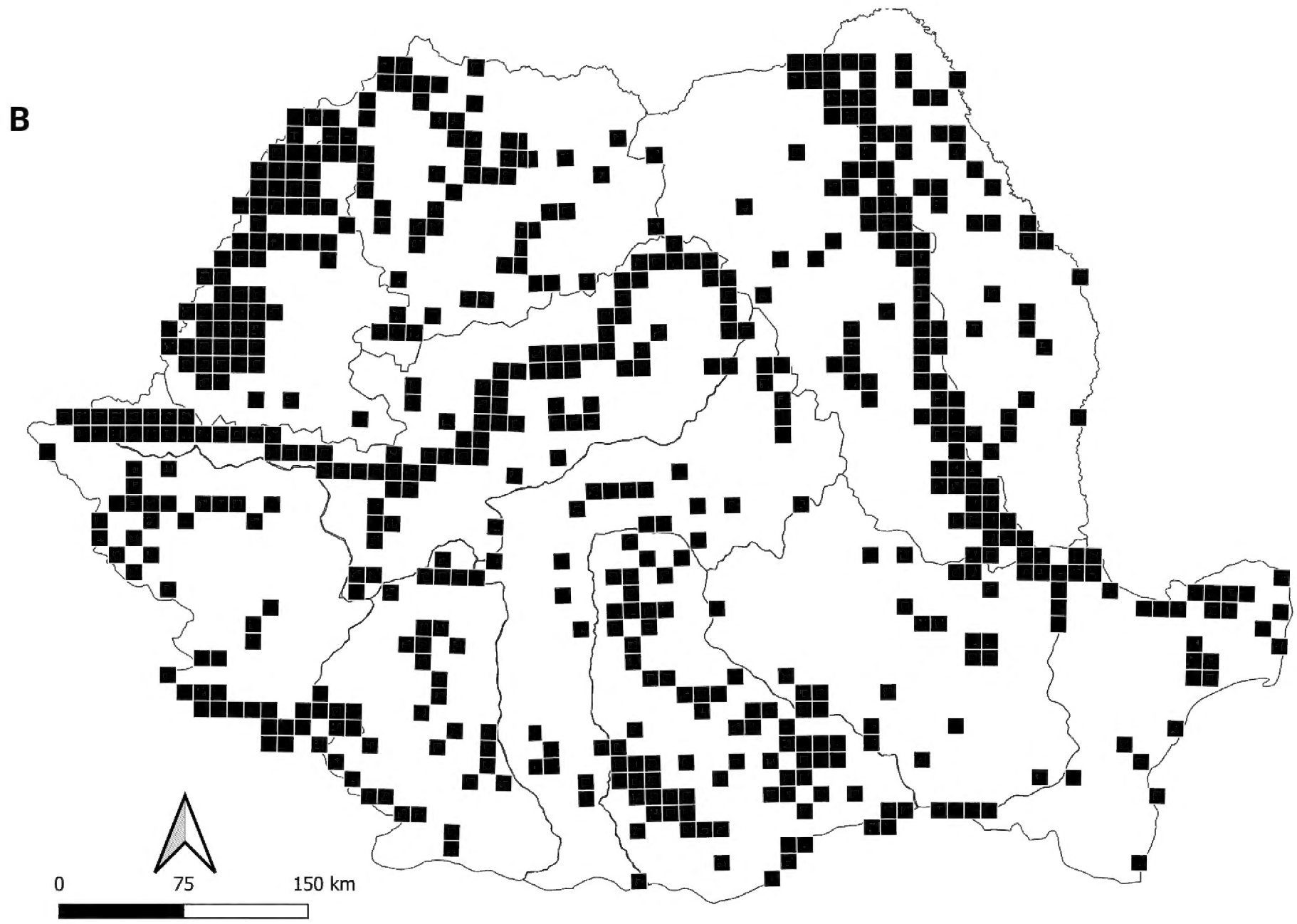


Figure 4. Invasive alien fish species occurrence records by river basin in Romania (**A**), and at UTM 10×10 km grid cell (**B**).

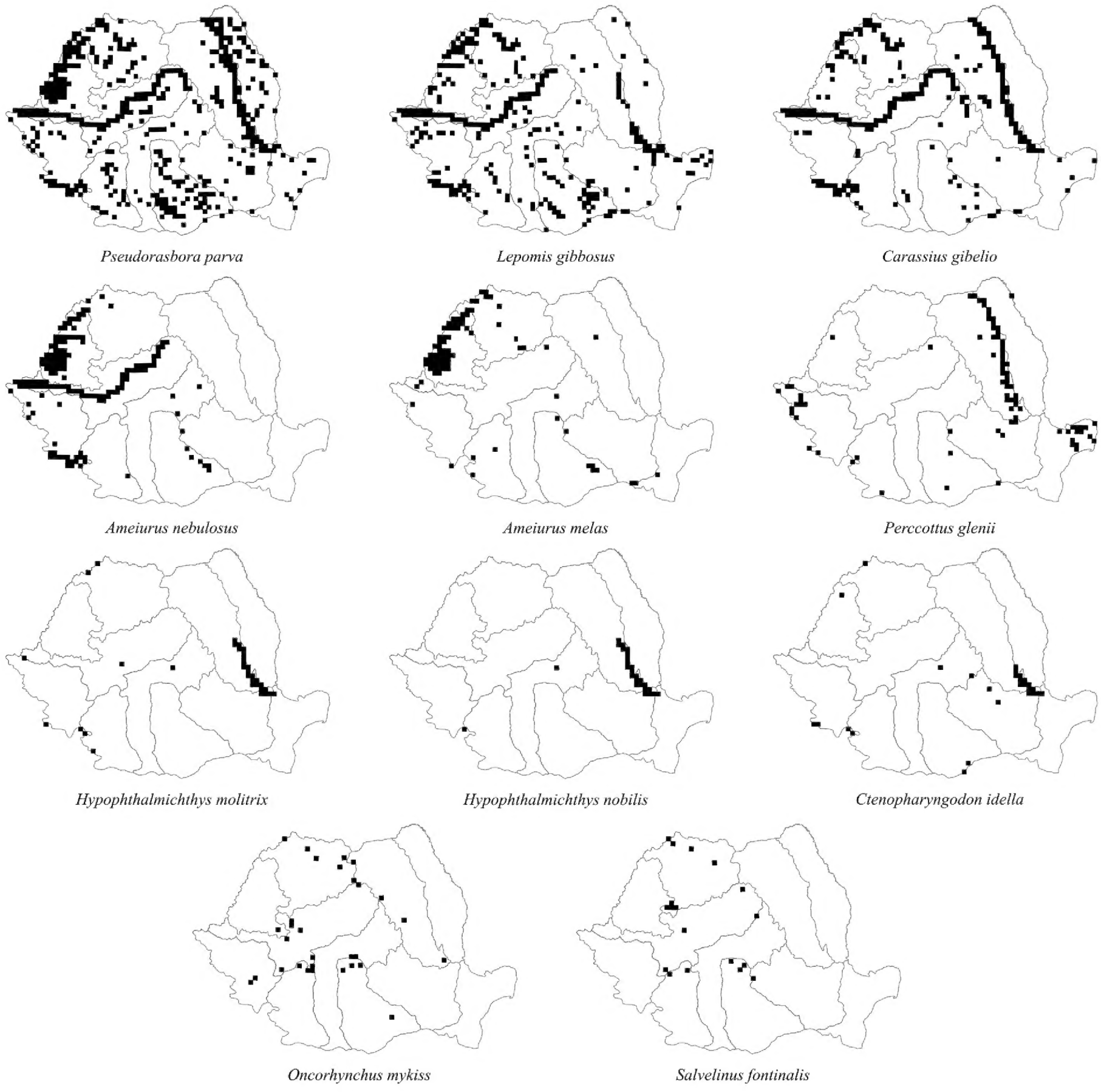


Figure 5. The occurrence records of invasive alien fish species in Romanian freshwater, by river basin unit, using UTM 10×10 km cells.

While not all alien species evolve to become invasive and have negative economic or ecological impacts, most invasive alien species share common characteristics such as rapid growth, broad environmental tolerance, and a history of invasiveness (Kolar and Lodge 2002; Docherty et al. 2017; Roy et al. 2024). For example, *Carassius gibelio* is probably the most common fish species in many lowland rivers in Romania (ANPA 2024) and it is the most caught species by fishermen, having a high commercial value (Eurofish Magazine 2021). However, at both the European and global levels, it is regarded as an invasive species with traits that impact ecosystems (Kucher et al. 2019; Šmejkal et al. 2024).

By mapping invasive alien fish distribution, we were able to identify several invasion hotspots, mostly along the north-western part of Romania and transboundary rivers, which correspond to the unaided pathway of introduction. We found that very few studies focused on the ecological impact of invasive alien fish species in Romania. This is likely because, until 1989, Romania was primarily focused on the exploitation of

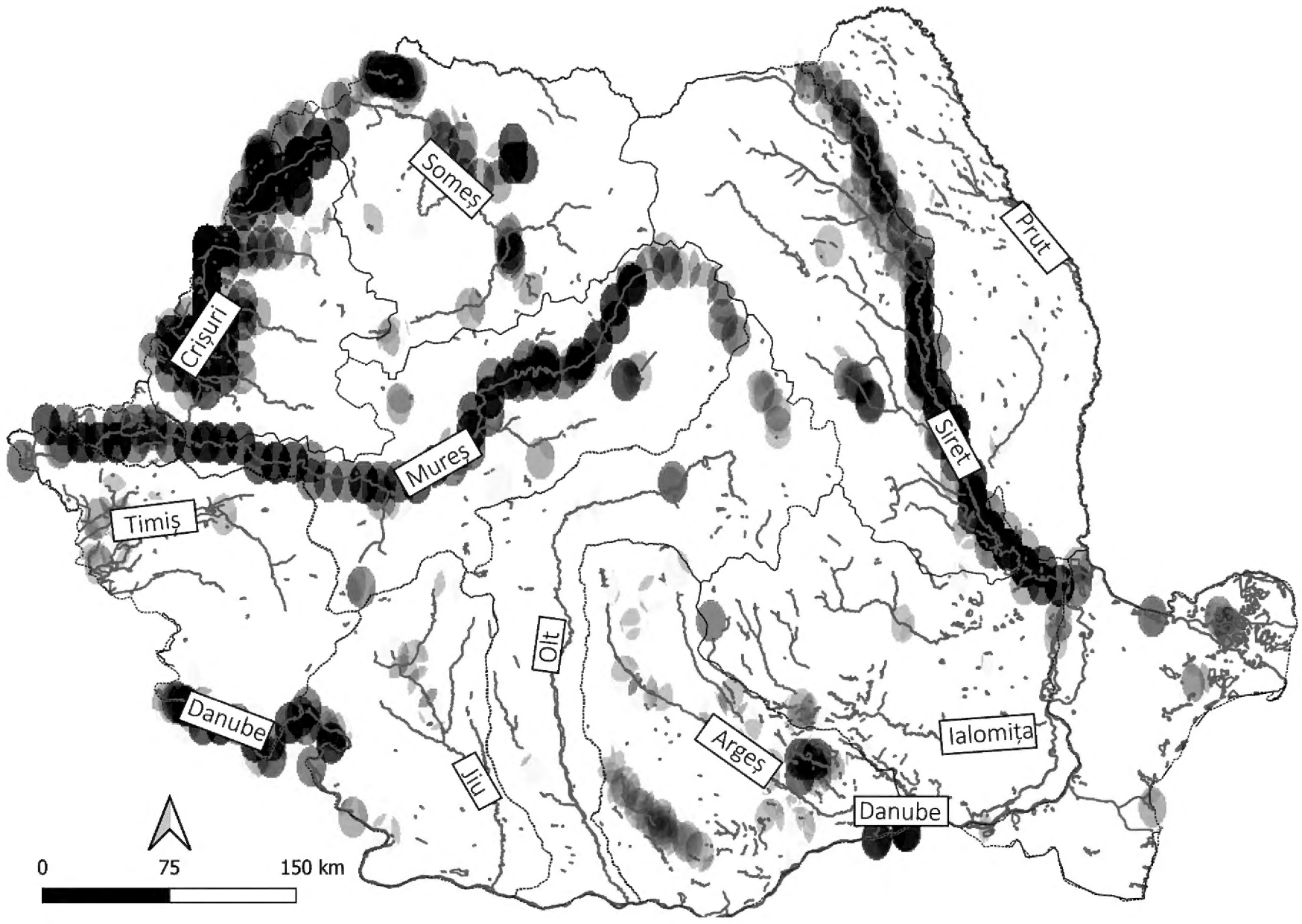


Figure 6. The hotspot map of invasive alien fish species across large rivers in Romania, using a greyscale with values from 1 (light) to 60 (dark) to present the number of occurrences in a 10 km radius.

economically valuable fish species, ignoring the evaluation of the invasive potential of introduced species (Petrisor and Tirziman 2019). The same practices have been reported and observed in neighbouring countries that also started fish introduction and acclimatisation campaigns prior to the 1970s, resulting in a similar timeline in alien species introductions reporting and numbers of alien fish species. For example, 31 alien fish species were reported in Bulgaria (Yankova 2016), while Takacs et al. (2017) reported 59 alien fish species in Hungary, with a large percentage due to aquarium releases, including *Carassius gibelio*, which is now a well-established invasive fish species (Keszte et al. 2021). In Serbia, an ESENIAS country report by Rat et al. (2016) identified 29 fish species as alien within that country, while in contrast, Lenhardt et al. (2011) reported a slightly lower number, citing 22 alien fish species. The primary pathway for the introduction of fish into Serbia is unaided spread through the Danube and Tisza rivers, originating from Romania and Hungary, as detailed by Lenhardt et al. (2011).

The Danube River, which connects approximately one-third of Europe and most Romanian rivers, plays a crucial role in the spreading and distribution dynamics of alien fish species (Bodis et al. 2012). The Balkan Peninsula is considered one of the hotspots of native freshwater fish diversity in Europe (Oikonomou et al. 2014) and, therefore, under significant threat from invasive alien species. The spread of alien freshwater species across natural barriers increased in the Danube basin after the construction of the Main-Rhine-Danube canal (Leuven et al. 2009; Paunovic et al. 2015). The need for coordinated actions resulted in the establishment of the Danube Region Invasive Alien Species (DIAS) Network in 2014 as part of the Priority Area 06 of the EU Strategy for the Danube Region (Rozylowicz et al. 2022).

We observed a spatial bias due to uneven spatial sampling. The data available might not be representative of the actual distribution of IAS in Romania but rather an indicator of the collectors of data, the so-called botanist effect (Moerman and Estabrook 2006; Anastasiu et al. 2024). Thus, the identified hotspots may primarily reflect areas with intensive, opportunistic sampling near major academic and research facilities rather than a systematic coverage. A second source of bias is due to accessibility, with many records originating from areas easily accessible, primarily in lowland or hilly regions. Comparatively, fewer records come from mountainous areas, where accessibility is often limited (Schmeller et al. 2022). To improve the accuracy of species distribution, researchers should systematically sample remote unprotected areas, distant from their research facilities.

Miu et al. (2020) identified protected areas of high priority for fish conservation in Romania, which overlap with the invasion hotspots found in our study. Within these areas, the Iron Gates Natural Park holds significance as the gateway of the Danube into Romania. This site and other important locations on the Romanian Danube shore are designated as RAMSAR sites (Rozylowicz et al. 2022). As designated priority areas for native fish protection, these RAMSAR sites face vulnerability to invasive alien fish species. The hotspots of invasive alien fish species overlap also with the Danube Delta Biosphere Reserve, a protected area hosting a substantial portion of native fish fauna (Rozylowicz et al. 2019).

The updated knowledge base on the distribution of alien fish in Romania is an outline of a complex and dynamic process. As invasive alien species continue to exploit the connectivity of river systems and spread, new areas face the threat of invasion. Furthermore, as climate change intensifies, affecting the hydrological cycle and making water levels increasingly unpredictable, this might eliminate physical barriers, allowing invasive alien fish species to expand and spread into new watersheds (Carosi et al. 2023; Le Hen et al. 2023). The dynamic range of invasive alien fish species due to the high connectivity requires proactive measures to prevent and contain their spread, and joint management strategies and agreements to coordinate efforts across national borders and effectively manage shared river systems (IPBES 2023).

Our study presents an updated occurrence database of invasive alien freshwater fish species in Romania. The database is a baseline for further inventories and monitoring the spread of invasive alien fish and is a valuable resource for conservation. As the threat of invasive alien species continues to grow, comprehensive and updated distribution mapping remains an essential tool for communication and effective environmental management.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization: DC, OD. Data curation: OD. Formal analysis: OD, DC. Investigation: DU, IF. Methodology: LR, DC. Project administration: DC. Writing – original draft: LR, DC, DU, OD, IF. Writing – review and editing: DU, DC, LR, IF, OD.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Methodology for classification of fish species into casual alien species, naturalized alien species, or invasive alien species

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Supplementary material 2

Publications used to compile occurrences distribution of invasive fish species in Romania

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